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THE SOLUTION OF CORROSION AND COAGULATION PROBLEMS AT MONTEBELLO FILTERS, BALTIMORE

By John R. Baylis[1]

Water which is corrosive to iron pipes is found in the supplies of a great many of our cities and is frequently the cause of numerous complaints. Many supplies originally not corrosive to an objectionable extent have been made so by chemical treatment, especially where alum is used as a coagulant. The most corrosive water is usually one whose hardness is below 100 p.p.m., and, in some instances when it is very low, it is necessary to use an alkali to reduce corrosion.

Efforts are being made at Baltimore to reduce the corrosion to a point where there are no complaints. The supply is obtained from the Gunpowder River and is filtered at Montebello Filters. Alum is used as a coagulant and lime is applied after filtration, unless occasionally a small amount is needed to produce a pH value sufficient for good coagulation.

The alkalinity of the water before treatment averages about 37 p.p.m., with a minimum of about 20 when the water is very turbid. The total hardness is about 42 p.p.m., and the free carbonic acid averages 5 p.p.m. The average amount of alum used is 1.2 grains per gallon, and, when applied at the average rate, reduces the alkalinity 8 to 10 p.p.m. and increases the free carbonic acid 5 to 10 p.p.m. The maximum application of alum is about 3.5 g.p.g. for very turbid water, which reduces the alkalinity about 27 p.p.m., and increases the free carbonic acid above 20 p.p.m.

The pH value before treatment averages 7 and is reduced to between 6 and 6.5 when the average amount of alum is added, and below 5 when the maximum amount is used. The terms increase and decrease in pH apply to the figures, which are the logs of the reciprocal of the hydrogen-ion concentration. Five is below the value necessary to obtain good coagulation, so at such times an alkali is applied near the same point as the alum.

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Since the filter plant was put in operation in 1915 and until 1918, iron and lime were used exclusively as coagulants, but since the latter period alum has been used part of the time in 1918, most of the time in 1919, and now all of the time. When iron and lime were used, good coagulation was hard to obtain unless the amount of lime used was high, so it was applied most of the time in quantities sufficient to give after filtration a monocarbonate alkalininity above 10 p.p.m. and a pH value from 9 to 9.5. This procedure resulted in encrusting the sand grains in the filter beds, greatly increasing their size, and encrusting slightly the pipes in the distribution system. Except for hot water pipes the corrosion was slight, although a heavy dose of chlorine increased it somewhat. Complaints of "red water" during this time were few and were confined almost entirely to hot water pipes.

Difficulty in obtaining satisfactory results when iron and lime were used, due partly to the character of the water and partly to insufficient time in the mixing basin, brought about a change to alum. This change resulted also in a lower cost for coagulant, as the alum was more effective and could be used in much smaller quantities, the ratio being about two to one.

When it was first used the incrustation on the sand grains in the filter beds, consisting mostly of carbonate of lime, reduced the free carbonic acid to about 1 p.p.m. There was very little increase in corrosion for some time, but by the latter part of 1919 most of the incrustation had dissolved from the sand grains and the free carbonic acid increased above that in the raw water. There was an increase in the iron contents of the water passing through the distribution system, and soon complaints from "red water" became very frequent.

Since October, 1919, lime to reduce corrosion has been used almost continuously. This method brought about other difficulties. Alum reacts best with a bicarbonate alkalinity. The application of lime, therefore, at approximately the same time as the alum greatly increased the amount of alum necessary to form good coagulation. Actual results compare fairly closely with experiments conducted at Jackson, Miss., in 1915 and 1916, on the effect of adding lime before alum.[2] No provision was made in construction for the application of lime at any point other that at the entrance to the mixing basin. Recommendations advising the application of lime after the water has passed through the coagulating basins and just before filtration were made, but instead of applying at the point recommended it was applied at the end of the mixing basin just before the water passes to the coagulating basins. This was a great improvement over the other point of application, but it was still found impossible to add enough lime at this point to reduce corrosion to the desired point, without increasing the amount of alum. It was also found that coagulation perfectly formed is partly redissolved by the addition of lime in small quantities. When the water was very turbid, requiring the use of from 2 to 3 g.p.g. alum, lime greatly affected the coagulation, if enough was added to reduce the free carbonic acid to nearly the neutral point. Consequently at times of high turbidity the lime was not increased in the same proportion as the alum, so the water was frequently very corrosive and caused complaints.

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[2] Engineering News-Record, Vol. 80, February 21, 1918, page 364.

In table 1 are shown the results of a few tests made to determine the amount of aluminum hydroxide dissolved by the application of lime at the outlet of the mixing basin, which is after the floc has been formed. Samples of filtered water from the two filter galleries were filtered through No. 40 Whatman's filter paper, one or two liters evaporated to dryness, and the iron and aluminum oxide determined gravimetrically No attempt was made to determine the iron oxide, but it averaged only about 0.2 p.p.m. in the combined filtered water and if most of it came from the north gallery it would not affect the results materially One grain per gallon of alum gives about 2.6 p.p.m. aluminum oxide (Al_2O_3), so these tests indicate that there is more aluminum oxide in the water from the north gallery, which is water that receives most of the lime, than was being applied. This is possibly due to aluminum compounds naturally in the water. Gravimetric determinations of the aluminum oxide in the composite monthly samples for August and September, after being filtered through alundum crucibles, average 1.5 p.p.m. The alumina in the filtered water is partly that naturally in the water and partly dissolved from the aluminum hydroxide. Lime was applied where it received only a partial mix in going to no. 1 settling basin, so some of the aluminum hydroxide was in contact with highly caustic water for a short time. It is safe to say that one-half of the floc in this basin was dissolved at times by application of lime at the outlet of the mixing basin.

The hydrogen-ion concentration determinations seem to offer a better indication of the corrosive qualities of water than other current

TABLE 1

Showing soluble iron and aluminum oxide in filtered water. All samples filtered through No. 40 Whatman filter paper: Gravimetric Determinations of Al_2O_3 and Fe_2O_3

DATE	TURBIDITY	GRAINS PER GALLON ALUM	ALKALINITY			FREE CARBONIC ACID			MONOCARBONATE ALKALINITY			pH			IRON AND ALUMINUM OXIDE P. P. M. Al_2O_3 AND Fe_2O_3		
			Mixing basin	North gallery	South gallery	Mixing basin	North gallery	South gallery	Mixing basin	North gallery	South gallery	Mixing basin	North gallery	South gallery	North gallery	South gallery	Mixing basin
1921																	
August 19	60	1.25											8.4	7.9	6.0	2.5	
August 22	88	1.25		47	40		1.8	4.0	0.0	0.0	0.0		7.8	7.2	4.1	1.7	
August 29	25	0.67		56	51		0.0	1.3		6.0	0.0		8.5	7.8	3.4	1.5	
August 30	23	0.60		54	51		0.0	1.7		4.0	0.0		8.4	7.7	3.0	2.2	
August 31	23	0.60		56	51		0.0	1.7		3.0	0.0		8.5	7.6	5.0	2.8	
September 1	23	0.55		53	48		0.0	3.1		2.0	0.0		8.4	7.5	3.4	1.4	
September 2	20	0.55		55	49		0.0	4.4		1.0	0.0		8.4	7.3	4.6	1.0	
September 16	140	1.82	19	34	28	20.7	4.8	9.7	0.0	0.0	0.0	6.0–	7.1	6.7	2.2	1.4	3.2
September 19	70	1.66	15	39	30	28.6	3.1	8.0	0.0	0.0	0.0	6.0–	7.5	6.7	2.4	1.6	1.0
September 30	60	0.64	37	49	45	10.6	6.0	4.0	0.0	3.0	0.0	6.7	8.4	7.4	3.7	1.6	1.2
Average.........	53	0.96	24	49	44	20.0	1.1	4.2	0.0	2.1	0.0	6.2–	8.1	7.4	3.8	1.8	1.8

Note: Lime is added to water at outlet of mixing basin, and does not mix thoroughly before it divides to go to the two settling basins. Consequently more lime goes to No. 1 settling basin than to No. 2. The effluent of the two basins are connected, but most of the water supplied the filters in the north gallery comes from basin No. 1, and the south gallery from basin No. 2. Mixing basin samples are before lime is added. Fe_2O_3 averages about 0.2 p.p.m. One litre samples from 8–19 to 9–2; two litre samples from 9–16 to 9–30.

tests. For some time, therefore, we have been trying to find a concentration that will be most suitable for the water supplied to Baltimore City. A hardness of 50 p.p.m., which is about the average of that supplied to the city, requires a pH value of about 8, in order to reduce corrosion in cold water pipes to a point where there will be practically no complaints. Realizing that complaints are made only when corrosion is fairly rapid, a pH value of from 8.5 to 9 has been tentatively set as that desired. The indications are that 8.5 is sufficient. Harder water may have a pH value lower than this, and for very hard water it may be about 7 without danger of excessive corrosion.

In the attempt to keep the water near the desired pH value, it was soon realized that some other point of application of the lime was necessary. Experiments on dissolving aluminum hydroxide with an alkali clearly indicated that the proper point of application was after filtration, and not before, as formerly recommended. Changes have been made in the lime pipe lines so as to apply it at this point. Evidence to date in handling a very variable character of water clearly indicates that this is the proper point to apply an alkali to reduce corrosion when alum is used as a coagulant. It is necessary to use some alkali to create proper coagulation, if the pH value goes below a certain point, which has been found to be about 5.5 for the water here under discussion. Almost complete precipitation is obtained when the pH is between 6 and 7, and fairly good when between 5.5 and 6, so no lime is applied at the entrance to the mixing basin unless the pH value goes below 5.5 after the application of alum, and then only enough to bring it to approximately this value. A greater amount causes an increase in the amount of alum necessary. We have no data on precipitation for values above 7, except experimental, as our raw water never goes above 7.4. When alum is applied in minimum amounts (0.4 grain per gallon) it reduces the pH to about 7. Added alkalinity, if bicarbonate, indicates that good precipitation can be obtained when the pH is considerably above 7.

Recent observations on the causes of turbid water passing the filters, and their correction are typical of conditions that have happened a number of times since alum has been used as a coagulant. These will give some indication of the importance of pH values in coagulation.

February 6, 1922. Raw water: turbidity 230, alkalinity 23, free carbonic acid 5 and pH 6.8; 2.5 grains per gallon alum applied, and after passing through mixing basin with about one-half hour mix contained: alkalinity 8, free carbonic acid 26.0 and pH 5.1. Coagulation was imperfect and turbidity after filtration was 5. Samples collected from outlet of mixing basin settled fairly rapid to a turbidity of about 10, then no appreciable change in seven hours. After settling over night the pH changed to 5.7, coagulated during the night and sedimentation was complete the next morning. As soon as the pH was found to be low the alum was reduced to 2 grains per gallon resulting in some improvement. The application of a small amount of lime to increase the pH to 5.6 helped considerably and results were very good but not perfect. Due to the turbidity and the effect of lime on the amount of alum necessary for coagulation, 2 grains per gallon was not enough and samples settling over night did not show perfect, nor any improvement after standing forty-eight hours, when they were discarded. A sample treated in the laboratory with 2 grains per gallon alum and stirred thirty minutes showed very good floc and settled rapidly to a turbidity of 8 in two hours, pH 5.4. No change in seven hours, but standing over night pH changed to 5.6, coagulation perfect and sedimentation complete. Laboratory sample treated with 1.5 grains per gallon alum and stirred thirty minutes showed perfect coagulation and complete sedimentation in two hours. The alum applied in the plant was reduced to 1.5 grains per gallon and the addition of lime with the alum stopped. Water thus treated showed good coagulation and filtered perfectly.

February 11, 1922. Raw water: turbidity 120, alkalinity 22, free carbonic acid 5 and pH 6.9; 1.82 grain per gallon alum produced very poor results, filter effluent having a turbidity of 4. Samples of effluent from the mixing basin showed: alkalinity 7, free carbonic acid 38.3 (very high but checked by several samples), pH 5.2. Settled to turbidity of 8 in two hours and showed no further change in seven hours. Settling twenty-four hours pH changed to 6, coagulation became perfect and settled completely. Alum reduced to 1.34 grain per gallon which showed an alkalinity of 15 and pH 6.5. Coagulation complete and filtered perfectly. Laboratory sample treated with 1 grain per gallon alum and stirred twenty minutes produced a good floc that settled rapidly to turbidity of 3. No change in forty-eight hours showed that this amount of alum was insufficient for proper coagulation.

These, and other results not reported here, show that the pH value should not go below 5.5 for good coagulation, and demonstrate also the advantage of pH values over alkalinity in determining if an alkali is needed with the alum. During only a very small per cent of the time at Baltimore is the pH reduced below 5.5 after the application of alum, but there are a number of cities treating water for filtration where the pH is reduced below this figure for a large percent of the time. Large plants with close supervision can adjust their waters to any desired hydrogen-ion concentration, but small plants with no chemist in charge may have some difficulty in producing good results. Possibly the best plan is to do as the author did a few years ago at Jackson, Miss. The settling basins were used in series and the lime was applied at the point where the water passed from one to the other. Most of the floc settled in the first basin, but frequently the water had a milky look before the lime was applied. At such times the water coagulated again in the second basin when lime was used. With our present knowledge of hydrogen-ions best results may possibly be obtained at this plant by applying a small amount of lime at approximately the same point as the alum to produce a pH of about 5.5 and applying the balance after filtration to prevent corrosion.

THE USE OF LIME TO PREVENT CORROSION

Many cities desire to prevent corrosion, yet it is surprising how few make any conscious attempt to do so. If iron and lime are used as coagulants it is necessary to have a high pH value (8.5 to 9.5) to produce good coagulation, so where these chemicals are used there are few complaints of corrosion. Iron is not suitable for all kinds of water, especially when highly colored, so alum will continue probably to be a most widely used coagulant. When used with soft water it will cause considerable corrosion of the service pipes, which can, and should be, reduced in many instances. The difficulties heretofore experienced in trying to use an alakli with alum has delayed its application in many instances, but with our present knowledge of coagulation processes it should become more extensively applied.

Considerable study has been given to the degree of corrosion causing complaints and its prevention. Extensive experiments were conducted to determine the total corrosive qualities of the Baltimore water supply, but not much of practical value was learned. It was shown that all the waters used attack pure iron with a bright surface very rapidly. Water with a pH of 5 attacked the entire surface, whereas that with a value of 9 corroded only in spots. The dissolved oxygen determines the total corrosion possible. If this were all used up in the Baltimore supply the life of iron pipes would be very short, possibly less than two years for wrought iron service pipes. The total corrosion possible is about 300 pounds of iron for each million gallons of water, or about 10,000,000 pounds yearly. With a bright surface exposed in 1½-inch wrought iron pipe, the iron contents of the water was increased about 15 p.p.m. in thirty minutes. This result shows the experiments on iron having a bright surface exposed are practically worthless. It is the rate of corrosion in service pipes, with partially protective coating, that concerns the water works official. The protective coating may be one applied by the manufacturer or it may be formed by the water passing through. Artificially applied coatings eventually wear off or dissolve from the pipes and protection then depends on the coating naturally formed.

To form some idea of the rate of corrosion taking place in the water pipes of Baltimore, daily tests have been made of the iron contents of the water leaving the filter plant and of that in the laboratory tap, which is water that has passed through several miles of cast iron mains. This sample gives possibly a fair idea of the total time of travel in the mains. The difference in iron between the two samples is a fair average of that going into solution or in suspension. How much remains as scale we are unable to tell, but it is possibly less than half of the above amount.

Comparison of iron, carbonic acid and dissolved oxygen in filtered water, p.p.m.

YEAR	IRON (Fe)		INCREASE IN IRON	FREE CO_2 FILTERED WATER	DISSOLVED OXYGEN
	Filtered	Laboratory tap			
1919	0.07	0.15	0.07	4.0	7.8
1920	0.10	0.21	0.11	6.6	7.8
1921	0.14	0.25	0.11	5.0	7.2

A study of the records indicates that, had no lime been applied, the iron contents would have been increased about 0.30 p.p.m. in passing through the cast iron mains. A large portion of the water passes through the wrought iron service pipes, which are more readily attacked, so that the actual increase in iron is greater than the laboratory sample shows. The total corrosion including the scale adhering to the pipes is estimated at 0.60 p.p.m. when lime is not used. The amount of water passing through the distribution system has averaged about 100,000,000 gallons daily for the past four years, so the total corrosion would be about 500 pounds daily if no lime were used. Leaks, damages to pavements and buildings, and cost of repairs, amount to a great deal per pound of pipe replaced. It may amount to as much as fifty cents per pound in some cities.

The use of 0.39 grain per gallon of lime, costing about $25.00 per day in 1921, reduced the corrosion to a total of approximately 0.22 p.p.m. The application of the lime after filtration as is now being done, to give a pH between 8.5 and 9, requires about 0.55 grain per gallon, costing about $35.00 per day. The total corrosion is reduced to at least 0.10 p.p.m., showing that the saving in piping is worth considerably more than the cost of lime used. Besides this procedure produces more palatable water. It has the disadvantage of making the water harder, requiring the use of more soap. Whipple, in "The Value of Pure Water," estimates that each person completely softens one gallon of water daily. Assuming that we have progressed somewhat in cleanliness, it is safe to estimate that 1,000,000 gallons is softened in Baltimore daily. The increase in soap hardness is about 10 p.p.m., which increases the amount of soap used about 2000 pounds per day, basing the estimate on laundry soap. The increase in cost of soap and the cost of lime may be somewhat greater than the value of the iron saved, but satisfaction has a value that will more than offset this difference, if there is any. If there were no depreciation in the pipes, water departments would be justified in preventing "red water." In Baltimore the total added cost for lime, soap, etc., amounts to only about 15 cents per year for each inhabitant. Comparing this with the amount we spend for satisfaction in food and clothes, it amounts to practically nothing.

The increase in iron contents of the water passing through the pipes is now kept at about 0.05 p.p.m., and represents a total corrosion of not over 0.10 p.p.m. for the amount consumed. Complaints from "red water" have ceased almost entirely. The ideal point is possibly where the tendency to encrust and corrode are at a minimum. Since we have found the pH value of this point to be about 8.5 for the water supplied to Baltimore, we have no difficulty in keeping corrosion reduced to a low rate.

METHOD OF MAKING PH DETERMINATIONS AT MONTEBELLO

Color standards are used in making the pH determinations. These standards are prepared according to the method recommended by Clark and Lubs, and sealed in 15 x 100 mm. pyrex tubes. These tubes are thoroughly cleaned, drawn at the top, filled with 10 cc. of the standard, and sealed. Standards are made for each 0.2 pH variation from 5.2 to 9.6. Brom-cresol purple (5.2–6.6), brom-thymol blue (6.2–7.4), phenol red (7.0–8.4) and thymol blue (8.2–9.6) are the indicators used. Solutions are made the strength recommended, and 0.5-cc. quantities are used both in the standards and the samples.

Sample bottles are thoroughly rinsed with water the same as the sample, then the sample collected and tested immediately. A tube the same size as the standard is thoroughly rinsed with the sample. A thoroughly cleaned 10-cc. pipette is filled with the sample, discarded, and another 10-cc. portion withdrawn and put in the tube. Five tenths cubic centimeters of the indicator is added to the tube, mixed, and a comparison made. Results are recorded to the nearest 0.1 pH value.

For clear solutions, or when slightly turbid, comparisons are made by holding the tubes against a white piece of paper. For accurate results a comparator block should be used if the turbidity is over 20, though fairly accurate results can be obtained with turbidities as high as 100.

The standards are kept in a dark room, except for a few minutes when in use. They are checked every two months, and if any show variations, they are replaced.